VOLTAGE TRACKING OF A DC-DC BUCK CONVERTER USING NEURAL NETWORK CONTROL

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For my beloved mother, father, wife, son and daughter

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ABSTRACT

This master report presents a voltage tracking of a neural network for dc-dc buck converter. The mathematical model of Buck converter and artificial neural network algorithm is derived. The dc-dc Buck converter is designed to tracking the output voltage with three variation. This master report consists open loop control, closed loop control and neural network control. The Buck converter has some advantages compare to the others type of dc converter. However the nonlinearity of the dc-dc Buck converter characteristics, cause it is difficult to handle by using conventional method such as open loop control system and close loop control system like proportional-integral-differential (PID) controller. In order to overcome this main problem, a neural network controller with online learning technique based on back propagation algorithm is developed. The effectiveness of the proposed method is verified by develop simulation model in MATLAB-Simulink program. The simulation results show that the proposed neural network controller (NNC) produce significant improvement control performance compare to the PID controller for both condition for voltage tracking output for dc-dc Buck converter.

ABSTRAK

Kertas ini membentangkan kaedah mengesan voltan keluaran menggunakan kaedah jaringan saraf (NNC). Model untuk matematik bagi penukar arus terus (AT-AT) jenis Buck dan jaringan saraf tiruan (ANN) algoritma diterbitkan. Penukar Buck direka untuk mengesan voltan keluaran dalam 3 variasi. Kertas ini merangkumi rekabentuk penukar Buck jenis kawalan gelung buka, gelung tertutup dan jaringan saraf (ANN). Penukar Buck mempunyai banyak kelebihan berbanding berbanding dengan penukar arus terus yang lain. Walau bagaimanapun, ciri-ciri ketidaklelurusan atau tidak linear penukar Buck arus terus terlalu sukar untuk dikawal, dan menyebabkan ia sukar untuk ditangani dengan menggunakan pembezaan penting berkadar konvensional (PID) pengawal. Untuk mengatasi masalah utama ini, pengawal jaringan saraf dengan teknik pembelajaran dalam talian berdasarkan algoritma penyebaran belakang dibangunkan. Keberkesanan cara yang disarankan ini terbukti dengan membangunkan model simulasi dalam program MATLAB-Simulink. Keputusan simulasi menunjukkan bahawa pengawal jaringan saraf pembelajaran yang dicadangkan itu (NNC) menghasilkan peningkatan prestasi kawalan yang sejajar dibandingkan dengan pengawal PID untuk mengesan voltan keluaran pengawal penukar Buck arus terus.

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Symbol

x	State vector
f	Function vector with n-dimension
u	Discontinuous control input
S	Sliding surface (manifold)
f^{+}, f^{-}	State velocity vector
f_N^{+}, f_N^{-}	Normal vectors
∇S	Gradient of sliding surface
e^{+}, e^{-}	Representative points
φ	Constant value
v_0	Output voltage
v_{con}	Control voltage
V_{ref}	Reference voltage
k_p, k_I	Proportional gain and integral gain of P-I controller
k_1	Voltage reduction factor
v_{ramp}	Sawtooth or Ramp voltage
V_U, V_L	Upper and Lower threshold voltages
q	Switching signal
h	Switching hypersurface
i_{ref}	Reference current

R_f	Proportionality factor
x_1	Voltage error
x_2	Voltage error dynamics
λ_1, λ_2	Line equations in phase plane
Δ	Small constant value
D	Diode
f_s	Switching frequency
T_S	Time period of external clock pulse
SMPS	Switched Mode Power Supply
CCM	Continuous Conduction Mode
DCM	Discontinuous Conduction Mode
SM	Sliding Mode
VSC	Variable Structure Control
VSS	Variable Structure System
PC	Proportional Control
PD	Proportional derivative Control
PID	Proportional integral derivative Control
EMI	Electromagnetic Interference
HM	Hysteresis Modulation
PWM	Pulse Width Modulation
GPI	Generalized proportional integral
PCCM	Pseudo continuous conduction mode
RP	Representative Point

CHAPTER 1

INTRODUCTION

1.1 Motivation

The switched mode dc-dc converters are some of the simplest power electronic circuits which convert one level of electrical voltage into another level by switching action. These converters have received an increasing deal of interest in many areas. This is due to their wide applications like power supplies for personal computers, office equipments, appliance control, telecommunication equipments, DC motor drives, automotive, aircraft, etc.

The commonly used control methods for dc-dc converters are pulse width modulated (PWM) voltage mode control, PWM current mode control with proportional (P), proportional integral (PI), and proportional integral derivative (PID) controller. These conventional control methods like P, PI, and PID are unable to perform satisfactorily under large parameter or load variation.

Therefore, the motivation of this thesis is to improve the voltage tracking performance of a dc-dc buck converter through neural network control (NNC). Hence, this thesis focused open loop circuit, closed loop circuit using proportional integral derivative (PID) and neural network control (NNC) for dc-dc buck converter circuit. The circuit is design with the equation and the comparison of voltage tracking is shown in this report.

1.2 Project Background

With rapid development in power electronic technology, power semiconductor technology, modern control theory for dc to dc converter such as buck converter and manufacturing technology for step down voltage in industry, buck converter have been widely used in many fields. Step down buck converter are integral to modern electronic [6]. Step down converter transfer small packets of energy using a switch, diode, an inductor and several application. Through subtantially larger and noisier than their linear regulater counterparts, buck converters offer higher effiency in most cases.

On the other hand, DC power supplies are often utilized to provide electric power supply not only for portable electronic devices such as notebook computers, but also for electric vehicle and aerospace applications. To provide the DC voltage source level requirements of the load to the DC power supply, the DC-DC converter widely used.

Moreover the DC-DC converter is also important in application such as power conditioning of the alternative electrical energy in photovoltaic, wind generator and full cell system. For these reason, DC-DC converter applications will become more potential market in the future.

Basically, the DC-DC converter consists of power semiconductor devices which are operated as electronic swtches. Operation of the switching devices causes the inherently nonlinear characteristic of DC-DC converter including one known as the Buck converter. Consequently, this converter requires are controller with a high degree of dynamic response. Proportional-Integral-Differential (PID) controllers have been usually applied to the converter because of their simplicity.

However implementations of this control method to the nonlinear plants such as the power converters will suffer from the dynamics response of the converter output voltage regulation.In the general, PID controller produces long rise time when the overshoot in output voltage decrease [9].

The study about neural network quickly developed in the past few decade in the control system has made great progress. Neural network reacted as an adaptive controller that has an ability to understand structure and parameters of controlled object and give the required control low without the accurate model of controlled object.

Therefore, neural network control method has good regulating capacity and robustness compared to Proportional-Integral-Differential (PID) control method [9].

To solve the problem, we can use intelligent controls, based on their ability to update the internal controller parameters, the nueral network control [NNC] are suitable for nonlinear system. Implementation of the NNC for DC-DC converter in computer simulation has been proposed. The develop online NNC has the ability to learn instantaneosly and adapt it own controller parameters based on external disturbance and internal variation of the converter with minimum steady state error, overshoot and rise time of the output voltage [1].

The back propogation (BP) neural network are capable to solve nonlinear control system and hence it can overcomes the problem that the conventional PID controller faced on difficulty to determine the parameters on line moment and effectively voltage tracking of buck converter , and it has a high value of practical application in the present neural network control.

1.2 Problem Statement

Most of the DC-DC converters such as Buck converter which is capable to step-down the output voltage produce higher current ripple. This will influenced and decreased the output voltage regulation and efficiency of the converter. This weaknesses can be overcomed by Buck converter which exhibit low input and output current ripple. Thus the efficiency of the converter will be increased. These factors also contribute to minimise the RFI, smaller size and weight.

The switching technique of the Buck converter causes the converter system to be nonlinear system. Nonlinear system requires a controller with higher degree of dynamic response. Proportional-Integral-Differential (PID) controllers has an advantages in term of simple structure and low cost.

However, PID controllers unable to adapt to the external disturbances and internal variations parameters and suffer from dynamic response of the system. PID controllers will produce higher overshoot, longer rise time and settling time which in turn will decreased the output voltage regulation of the Buck converter [7].

1.3 Project Objectives

The objectives of this project are:-

i. To show the voltage tracking of Buck converter using open loop control

ii. To improve the performance of Buck converter using PID controller (such as reduce overshoot, rise time and steady state error).

iii. To develop simulation of voltage tracking Buck converter using Neural Network Control (NNC) method.

iv. To compare the analysis for PID controller and Neural Network Control.

1.4 Project Scopes

The scopes of this project is to simulate the proposed method of voltage tracking Buck converter by using Neural Network Controller (NNC) with MATLAB Simulink software. The Neural Network Controller (NNC) learning developed in this project will use three layers with one neurons at input layer, three neurons at the hidden layer followed with an output layer.

1.5 Thesis Overview

Chapter 1 describes about motivation, project background, problem statement, project objectives and project scope for dc-dc buck converter. In chapter 2**,** a detailed explanation and classification of techniques for switched mode power supplies have been given. The chapter also defined and summarized, with the aid of mathematical equations for dc-dc buck converter.

The information about the different modes of operations that are continuous conduction mode (CCM), discontinuous conduction mode (DCM) has been given. Chapter 3 gives a detail study of methodology to build a Neural Network circuit for dc-dc buck converters. Chapter 4 shows the analysis for open loop, closed loop using pid and neural network using buck converter circuit. Lastly, a conclusion for this research is mention in chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Technology Development

Switch mode DC-DC converters efficiently convert an unregulated DC input voltage into a regulated DC output voltage. Compared to linear power supplies, switching power supplies provide much more efficiency and power density. Switching power supplies employ solid-state devices such as transistors and diodes to operate as a switch either completely on or completely off [4].

Energy storage elements including capacitors and inductors, are used for energy transfer and work as a low-pass filter. The buck converter and the boost converter are the two fundamental topologies of switch mode DC-DC converters. Most of the other topologies are either buck-derived or boost-derived converters, because their topologies are equivalent to the buck or the boost converters [2].

Traditionally, the control methodology for DC-DC converters has been analog control. In the recent years, technology advances in very-large-scale integration (VLSI) have made digital control of DC-DC converters with microcontrollers and digital signal processors (DSP) possible.

The major advantages of digital control over analog control are higher immunity to environmental changes such as temperature and changing of components, increased flexibility by changing the software, more advanced control techniques and shorter design cycles.

2.2 Switch-Mode DC-DC Converters

Switch-mode DC-DC converters are used to convert the unregulated DC input to a controlled DC output at a desired voltage level. Switch-mode DC-DC converters include buck converters, boost converters, buck-boost converters, Cuk converters and full-bridge converters, etc. Among these converters, the buck converter and the boost converter are the basic topologies. Both the buck-boost and Cuk converters are combinations of the two basic topologies. The full-bridge converter is derived from the buck converter [12].

The dc-dc switching converters are the widely used circuits in electronics systems. They are usually used to obtain a stabilized output voltage from a given input DC voltage which is lower (buck) from that input voltage, or higher (boost) or generic (buck–boost) [1]. Most used technique to control switching power supplies is Pulse-width Modulation (PWM) [2]. The conventional PWM controlled power electronics circuits are modeled based on averaging technique and the system being controlled operates optimally only for a specific condition [3]-[4]. The linear controllers like P, PI, and PID do not offer a good large-signal transient (i.e. large-signal operating conditions) [4]-[5]

There are usually two modes of operation for DC-DC converters: continuous and discontinuous. The current flowing through the inductor never falls to zero in the continuous mode. In the discontinuous mode, the inductor current falls to zero during the time the switch is turned off. Only operation in the continuous mode is considered in this dissertation. Therefore, research has been performed for investigating voltage tracking of dc-dc buck converter.

2.3 Theory of Operation Buck Converter

The operation of the buck converter is fairly simple, with an inductor and two switches (usually a transistor and a diode) that control the inductor. It alternates between connecting the inductor to source voltage to store energy in the inductor and discharging the inductor into the load.

The buck converter, shown in Figure 2.1, converts the unregulated source voltage Vin into a lower output voltage Vout. The NPN transistor shown in Figure 1 works as a switch. The ratio of the ON time (t_{ON}) when the switch is closed to the entire switching period (T) is defined as the duty cycle D = t_o/T. The corresponding PWM signal is shown in Figure 2.2 [10].

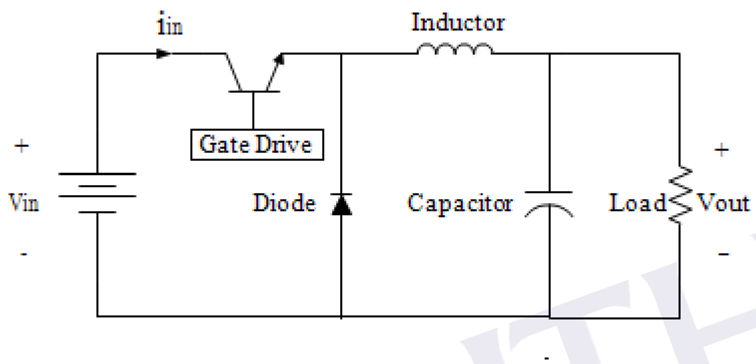

Figure 2.1: Buck Converter Circuit

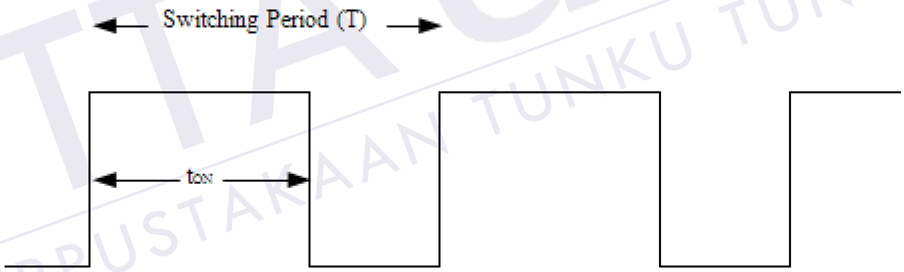

Figure 2.2: PWM signal to control the switches in the DC-DC converter

The equivalent circuit in Figure 2.3 is valid when the switch is closed. The diode is reverse biased, and the input voltage supplies energy to the inductor, capacitor and the load. When the switch is open as shown in Figure 2.4, the diode conducts, the capacitor supplies energy to the load, and the inductor current flows through the capacitor and the diode [2]. The output voltage is controlled by varying the duty cycle. On steady state, the ratio of output voltage over input voltage is D, given by *Vout/ Vin*.

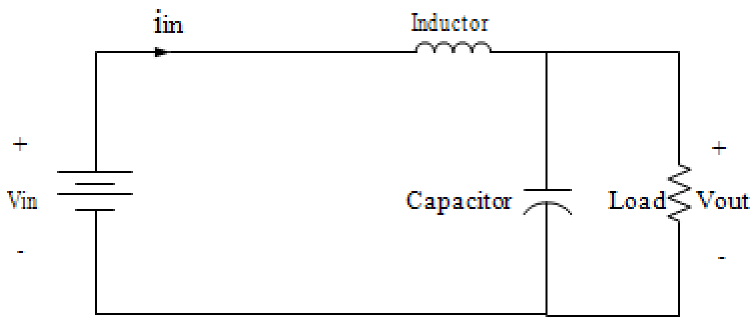

Figure 2.3: Equivalent circuit of the buck converter
when the switch is closed

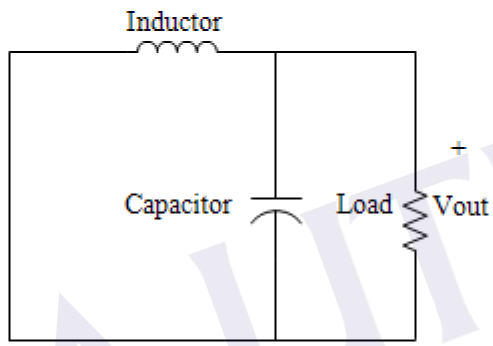

Figure 2.4: Equivalent circuit of the buck converter
when the switch is open

A buck converter is a step-down DC to DC converter. Its design is similar to the step-up boost converter, and like the boost converter it is a switched-mode power supply that uses two switches (a transistor and a diode), an inductor and a capacitor.

The buck converter reducing the dc voltage, using only nondissipative switches, inductors, and capacitors. The switch produces a rectangular waveform $v_s(t)$ as illustrated in Figure 2.5. The voltage $v_s(t)$ is equal to the dc input voltage V_g when the switch is in position *1*, and is equal to zero when the switch is in position *2*.

In practice, the switch is realized using power semiconductor devices, such as transistors and diodes, which are controlled to turn on and off as required to perform the function of the ideal equal to the inverse of the switching period T_s, generally lies in the range of switching speed of the semiconductor devices.

The duty ratio *D* is the fraction of time which the switch spends in position *1*, and is a number between zero and one. The complement of the duty ratio, *D'*, is defined as (1-*D*) [2].

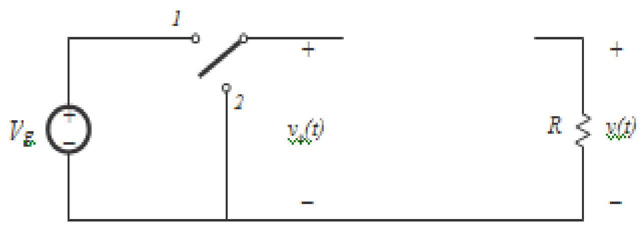

Figure 2.5: Ideal switch, (a) used to reduce the voltage dc component

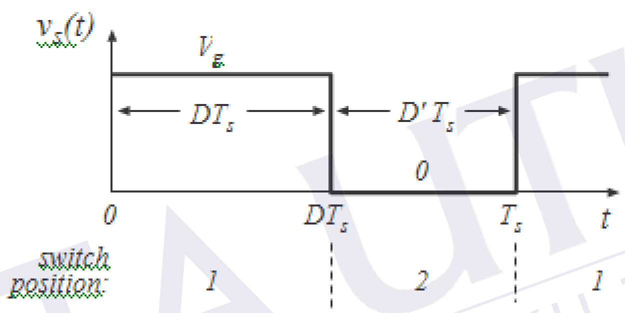

Figure 2. 6:(b) its output voltage waveform $v_S(t)$.

The switch reduces the dc component of the voltage: the switch output voltage $v_s(t)$ has a dc component which is less than the converter dc input voltage V_g. From Fourier analysis, we know that the dc component of $v_s(t)$ is given by its average value $<v_s>$, or

$$< Vs > = \frac{1}{Ts}\int_0^{T} Vs(t)\,dt \qquad (2.1)$$

As illustrated in Figure 2.7, the integral is given by the area under the curve, or DT_sV_g. The average value is therefore

$$< Vs > = \frac{1}{Ts}(DTsVg) = DVg \qquad (2.2)$$

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